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(54) **Mems tuning fork gyro sensitive to rate of rotation about two axes**

Auf Rotationsrate um zwei Achsen sensitiver MEMS-Stimmgabelkreisel

Gyroscope à diapason MEMS sensible à la vitesse de rotation autour de deux axes

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Description

BACKGROUND OF THE INVENTION

[0001] In many inertial measurement systems, there is a need for measuring rotation about three orthogonal axes. Traditionally, measuring rate of rotation about three orthogonal axes is performed by three separate sensors (gyroscopes). Because each sensor consumes valuable space and is a very sensitive and expensive device, the cost of inertial measurement systems is quite large.

[0002] Therefore, there exists a need for reducing the complexity and cost of sensors and inertial measurement systems or comparable systems.

SUMMARY OF THE INVENTION

[0003] The present invention is defined by the appended claims.

[0004] The present invention provides a two-axes MEMS gyroscope system. The system includes two proof masses, two drive combs, two drive sense combs, two Coriolis sense electrodes sensitive to out-of-plane proof mass motion, two Coriolis sense electrodes sensitive to in-plane proof mass motion, and a processing device. The processing device is in signal communication with the two proof masses, the drive electrodes, the drive sense combs, the in plane Coriolis sense electrodes and the out of plane Coriolis sense electrodes. The processing device determines the rate of rotation about two orthogonal axes based on signals received from the two proof masses or the four Coriolis electrodes.

[0005] The two drive combs and the two drive sense combs form comb capacitors with respective proof masses.

[0006] In one aspect of the invention, bias voltages on the in-plane Coriolis sense electrodes are modulated at a first modulation frequency and the out-of-plane Coriolis sense electrodes are biased at a second modulation frequency. The processing device demodulates the signals received from the proof masses based on two previously defined modulation frequencies.

[0007] In another aspect of the invention, the proof masses are biased to predefined voltages. The processing device receives independent signals from the two sets of Coriolis electrodes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Preferred and alternative embodiments of the present invention are described in detail below with reference to the following drawings:

FIGURE 1 illustrates a top-down view of an example two axes sensing gyro system formed in accordance with an embodiment of the present invention;

FIGURE 2 illustrates a partial cross sectional view of the system of FIGURE 1; and

FIGURE 3 illustrates a sensor system formed in accordance with an alternate embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0009] FIGURES 1 and 2 illustrate an example of a Micro ElectroMechanical Systems (MEMS) sensor 20 that measures rate of rotation about two orthogonal axes. The sensor 20 includes two tuning fork proof masses 24, 26, a motor charge amplifier 44, a sense charge amplifier 50, a processing device 54, and an output device 56. The proof masses 24, 26 are located above a substrate that includes Coriolis sense electrodes 40 and 42, which are sensitive to out-of plane proof mass motions. The sensor 20 also includes two in-plane Coriolis sense electrodes 63, which are sensitive to in-plane proof mass motions.. Motor driver components 60 are electrically connected to drive combs 62. The motor charge amplifier 44 is electrically connected to sense combs 64.

[0010] The proof masses 24, 26 are driven to oscillate at resonance in an X direction. The proof masses 24, 26 are driven to oscillate out of phase by the motor driver components 60. On opposing sides of the proof masses 24, 26 are tines that are interleaved with tines of the drive sense combs 64. The motor charge amplifier 44 outputs a motor signal to the processing device that generates motor driver signals that are sent to the motor drive combs 62 via the motor driver component 60 in order to make sure that the proof masses 24, 26 are driven at the mechanical resonant frequency.

[0011] The in-plane Coriolis sense electrodes 63, are asymmetric from the motor drive and drive sense combs 62, 64 of the proof mass 26 in order to allow detection of capacitance change for motion of the proof masses 24, 26 in the Y direction, induced by rotation about the Z axis (the direction perpendicular to the motor motion).

[0012] In a first embodiment, both proof masses 24, 26 are electrically connected to the charge amplifier 50 for outputting a voltage signal to the processing device 54. The outputted voltage signal is received by the processing device 54. The voltage signal that is applied to the in-plane Coriolis electrodes 63 is modulated at a first frequency and a voltage signal applied to the out of plane Coriolis electrodes 40 and 42 are modulated at a second frequency that is different than the first frequency. The processing device 54 includes demodulators that demodulate both of the modulation frequencies. The modulation frequencies would be far removed from mechanical resonances of the sensor 20. After the processing device 54 demodulates the received signal based on the first frequency, the processing device 54 analyzes the demodulated signal to determine if a rate of rotation has occurred about the Z-axis. Next, the processing device 54 demodulates the signals received at the second modulation frequency to determine the rate of rotation about the Y-axis. The determined rate of rotation values are outputted via the output device 56.

[0013] FIGURE 3 illustrates another example system 70 for sensing rate of rotation about two separate axes. The system 70 includes the same motor drive component 60 proof masses 24, 26, electrodes 40a, 42a, and combs 62, 64 as FIGURE 1. The system 70 includes a processing device 74 that receives signals from the electrodes 40a, 42a and from the sense combs 63. In this example, the proof masses 24, 26 are biased to a predefined voltage, such as ground. In one embodiment, the separate processing device 54 is two separate devices for determining rate of rotation values for each axis of rotation. The determined rate of rotation values are outputted via an output device 56.

Claims

1. A two-axes MEMS gyroscope system (20, 70) comprising:

   two proof masses (24, 26);
   two drive combs (62) configured to drive the proof masses (24, 26) to resonate in plane;
   two drive sense combs (64); four Coriolis sense electrodes (63, 40, 42), two of the Coriolis sense electrodes (63) are sensitive to in-plane proof mass motion and two of the Coriolis sense electrodes (40, 42) are sensitive to out-of-plane proof mass motion;
   a processing device (54, 74) in signal communication with at least one of:

      the two proof masses; or
      the four Coriolis sense electrodes; **characterised in that** bias voltages on the in-plane Coriolis sense electrodes are modulated at a first modulation frequency and the out-of-plane Coriolis sense electrodes are biased at a second modulation frequency; and
      the processing device (54, 74) includes demodulators that demodulate signals received from the two proof masses or the four Coriolis sense electrodes based onboth of the first and second modulation frequencies, wherein after the processing device (54, 74) demodulates the received signal based on the first frequency, the processing device analyzes the demodulated signal to determine a rate of rotation about the Z-axis, and the processing device demodulates the signals received at the second modulation frequency to determine the rate of rotation about the Y-axis.

2. The system (20, 70) of Claim 1, wherein the two drive combs (62) and the two drive sense combs (64) form comb capacitors with a respective proof mass (24, 26).

3. A method for determining rate of rotation about two orthogonal axes in a single MEMS gyroscope system (20, 70), the method comprising:

   driving a first and a second proof mass (24, 26) to resonate in plane based on a drive signal by two drive combs (62) **characterised by** modulating two of four Coriolis sense electrodes (63), sensitive to in-plane motions of the first and second proof masses, at a first frequency;
   modulating another two of the four Coriolis sense electrodes (40, 42), sensitive to out-of-plane motions of the first and second proof masses, at a second frequency;
   receiving signals from at least one of: the two proof masses; or the four Coriolis sense electrodes;
   demodulating the received signal based on the first frequency at a processing device (54, 74) that includes demodulators;
   analyzing the demodulated signal based on the first frequency to determine a rate of rotation about the Z-axis;
   demodulating the received signal based on the second frequency at the processing device (54, 74); and
   analyzing the demodulated signal based on the second frequency to determine a rate of rotation about the Y-axis.

4. The method of Claim 3, wherein the two drive combs (62) and two drive sensing combs (64) form comb capacitors with a respective proof mass (24, 26).

Patentansprüche

1. Zweiachsen-MEMS-Kreiselsystem (20, 70), umfassend:

   zwei Prüfmassen (24, 26);
   zwei Antriebskämme (62), die konfiguriert sind, um die Prüfmassen (24, 26) anzutreiben, damit sie in der gleichen Ebene schwingen;
   zwei Antriebserfassungskämme (64);
   vier Coriolis-Erfassungselektroden (63, 40, 42), wobei zwei Coriolis-Erfassungselektroden (63) empfindlich für eine Bewegung der Prüfmassen in der gleichen Ebene sind und wobei zwei Coriolis-Erfassungselektroden (40, 42) empfindlich für eine Bewegung der Prüfmassen aus der Ebene sind;
   eine Verarbeitungsvorrichtung (54, 74), die in einer Signalkommunikation steht mit mindestens einer von:

den beiden Prüfmassen; oder
den vier Coriolis-Erfassungselektroden;
dadurch gekennzeichnet, dass,
Vorspannungen in den Coriolis-Erfassungselektroden der gleichen Ebene mit einer ersten Modulationsfrequenz moduliert werden und die Coriolis-Erfassungselektroden außerhalb der Ebene mit einer zweiten Modulationsfrequenz vorgespannt werden; und
die Verarbeitungsvorrichtung (54, 74) Demodulierеinheiten umfasst, welche die Signale demodulieren, die von den beiden Prüfmassen oder den vier Coriolis-Erfassungselektroden auf der Grundlage der ersten und der zweiten Modulationsfrequenz empfangen werden,
wobei, nachdem die Verarbeitungsvorrichtung (54, 74) das empfangene Signal auf der Grundlage der ersten Frequenz demoduliert hat, die Verarbeitungsvorrichtung das demodulierte Signal analysiert, um eine Rotationsrate um die Z-Achse zu ermitteln, und wobei die Verarbeitungsvorrichtung das auf der zweiten Demodulationsfrequenz empfangene Signal demoduliert, um die Rotationsrate um die Y-Achse zu ermitteln.

2. System (20, 70) nach Anspruch 1, wobei die beiden Antriebskämme (62) und die beiden Antriebserfassungskämme (64) Kammkondensatoren mit einer entsprechenden Prüfmasse (24, 26) bilden.

3. Verfahren zum Ermitteln einer Rotationsrate um zwei orthogonale Achsen in einem einzigen MEMS-Kreiselsystem (20, 70), wobei das Verfahren umfasst:

Antreiben einer ersten und einer zweiten Prüfmasse (24, 26), um auf der Grundlage eines Antriebssignals von den beiden Antriebskämmen (62) in der gleichen Ebene zu schwingen,
gekennzeichnet durch:

Modulieren von zwei aus vier Coriolis-Erfassungselektroden (63), die für Bewegungen der ersten und der zweiten Prüfmasse mit einer ersten Frequenz in der gleichen Ebene empfindlich sind;
Modulieren der anderen beiden der vier Coriolis-Erfassungselektroden (40, 42), die für Bewegungen der ersten und der zweiten Prüfmasse mit einer zweiten Frequenz außerhalb der Ebene empfindlich sind;
Empfangen von Signalen von mindestens einer von: den beiden Prüfmassen; oder den vier Coriolis-Erfassungselektroden;
Demodulieren in einer Verarbeitungsvorrichtung (54, 74), die Demodulierеinheiten umfasst, des auf der Grundlage der ersten Frequenz empfangenen Signals;
Analysieren des demodulierten Signals auf der Grundlage der ersten Frequenz, um eine Rotationsrate um die Z-Achse zu ermitteln;
Demodulieren in einer Verarbeitungsvorrichtung (54, 74)des auf der Grundlage der zweiten Frequenz empfangenen Signals; und
Analysieren des demodulierten Signals auf der Grundlage der zweiten Frequenz, um eine Rotationsrate um die Y-Achse zu ermitteln.

4. Verfahren nach Anspruch 3, wobei die beiden Antriebskämme (62) und die beiden Antriebserfassungskämme (64) Kammkondensatoren mit einer entsprechenden Prüfmasse (24, 26) bilden.

Revendications

1. Système de gyroscope à capteur micro électromécanique MEMS à deux axes (20, 70) comprenant :

deux masses d’épreuve (24, 26),
deux peignes d’entraînement (62) configurés pour entraîner les masses d’épreuve (24, 26) pour qu’elles résonnent dans un plan,
deux peignes de détection d’entraînement (64),
quatre électrodes de détection de force de Coriolis (63, 40, 42), deux des électrodes de détection Coriolis (63) étant sensibles au mouvement de masses d’épreuve dans le plan et deux des électrodes de détection Coriolis (40, 42) étant sensibles au mouvement de masses d’épreuve hors du plan,
un dispositif de traitement (54, 74) en communication par signaux avec au moins l’un parmi :

les deux masses d’épreuve, ou
les quatre électrodes de détection Coriolis,
caractérisé en ce que les tensions de polarisation sur les électrodes de détection Coriolis dans le plan sont modulées à une première fréquence de modulation et les électrodes de détection Coriolis hors du plan sont polarisées à une seconde fréquence de modulation, et
le dispositif de traitement (54, 74) inclut des démodulateurs qui démodulent les signaux reçus en provenance des deux masses d’épreuve ou des quatre électrodes de détection Coriolis sur la base des première et seconde fréquences de modulation, où,

après que le dispositif de traitement (54, 74) a démodulé le signal reçu sur la base de la première fréquence, le dispositif de traitement analyse le signal démodulé pour déterminer un taux de rotation autour de l'axe Z, et le dispositif de traitement démodule les signaux reçus à la seconde fréquence de modulation afin de déterminer le taux de rotation autour de l'axe Y.

2. Système (20, 70) selon la revendication 1, dans lequel les deux peignes d'entraînement (62) et les deux peignes de détection d'entraînement (64) forment des condensateurs en peignes avec une masse respective d'épreuve (24, 26).

3. Procédé de détermination du taux de rotation autour de deux axes orthogonaux dans un système unique de gyroscope à capteurs micro électromécaniques MEMS (20, 70), le procédé comprenant :

l'entraînement d'une première et d'une seconde masse d'épreuve (24, 26) pour qu'elles résonnent dans un plan sur la base d'un signal d'entraînement généré par deux peignes d'entraînement (62),
caractérisé par :

la modulation de deux des quatre électrodes de détection de force de Coriolis (63), sensibles à des mouvements dans le plan des première et seconde masses d'épreuve à une première fréquence,
la modulation de deux autres des quatre électrodes de détection Coriolis (40, 42) sensibles à des mouvements hors du plan des première et seconde masses d'épreuve à une seconde fréquence,
la réception de signaux provenant d'au moins l'une parmi : les deux masses d'épreuve ou les quatre électrodes de détection Coriolis,
la démodulation du signal reçu sur la base de la première fréquence grâce à un dispositif de traitement (54, 74) qui inclut des démodulateurs,
l'analyse du signal démodulé sur la base de la première fréquence afin de déterminer un taux de rotation autour de l'axe Z,
la démodulation du signal reçu sur la base de la seconde fréquence grâce au dispositif de traitement (54, 74), et
l'analyse du signal démodulé sur la base de la seconde fréquence afin de déterminer le taux de rotation autour de l'axe Y.

4. Procédé selon la revendication 3, dans lequel les deux peignes d'entraînement (62) et les deux peignes de détection d'entraînement (64) forment des condensateurs en peignes avec une masse respective d'épreuve (24, 26).

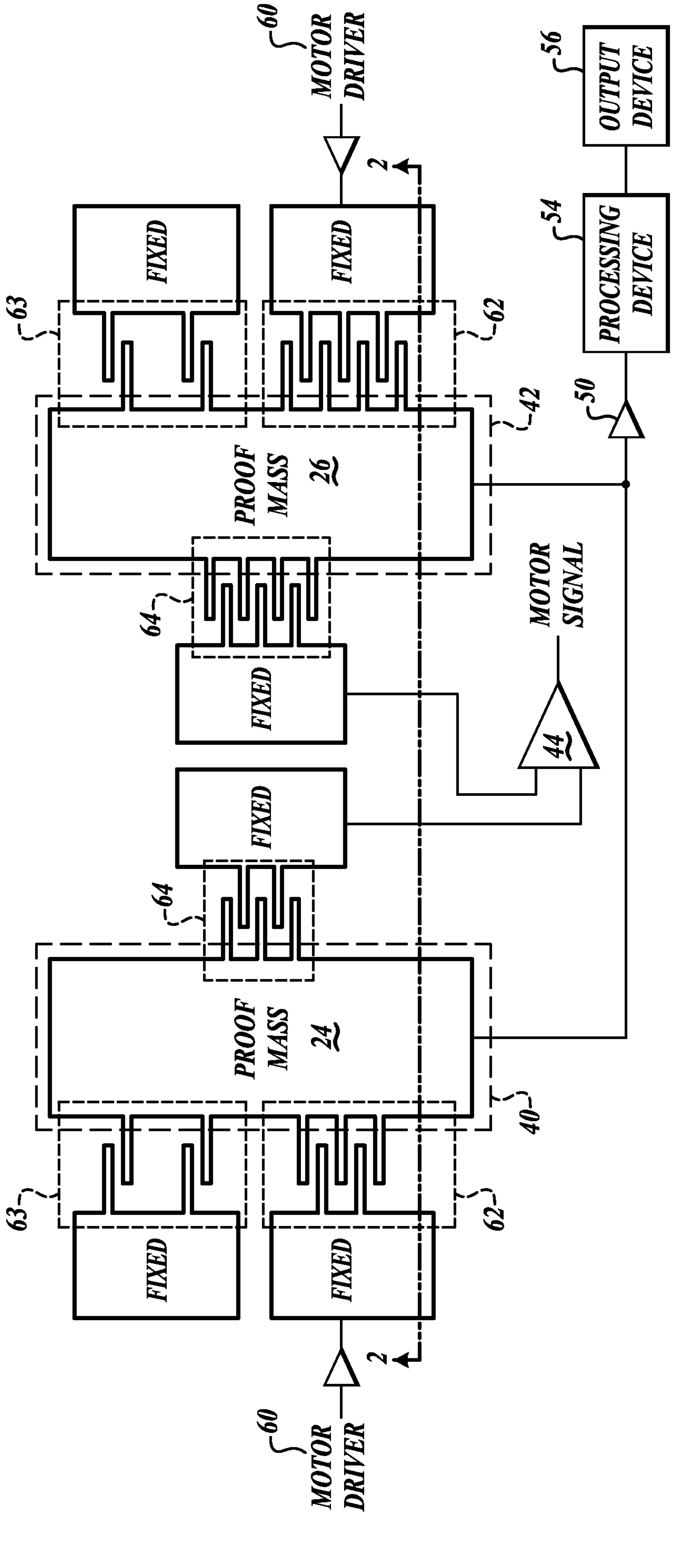
MOTOR DRIVER
60
2
FIXED
FIXED
63
62
42
PROOF MASS 26
64
FIXED
FIXED
44
MOTOR SIGNAL
50
PROCESSING DEVICE
54
OUTPUT DEVICE
56
64
PROOF MASS 24
40
63
62
FIXED
FIXED
2
MOTOR DRIVER
60

FIG.1

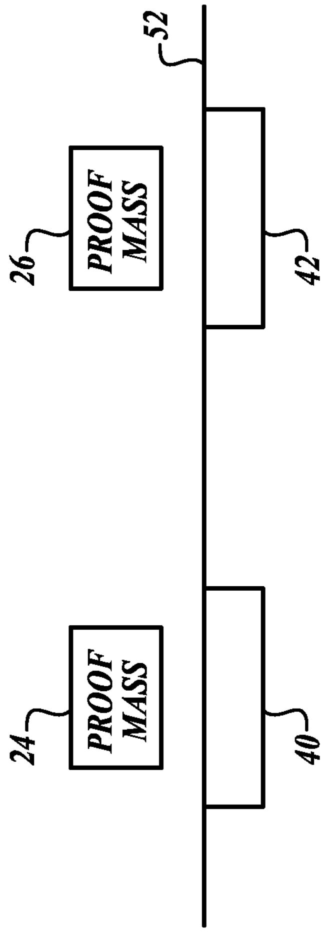

FIG.2

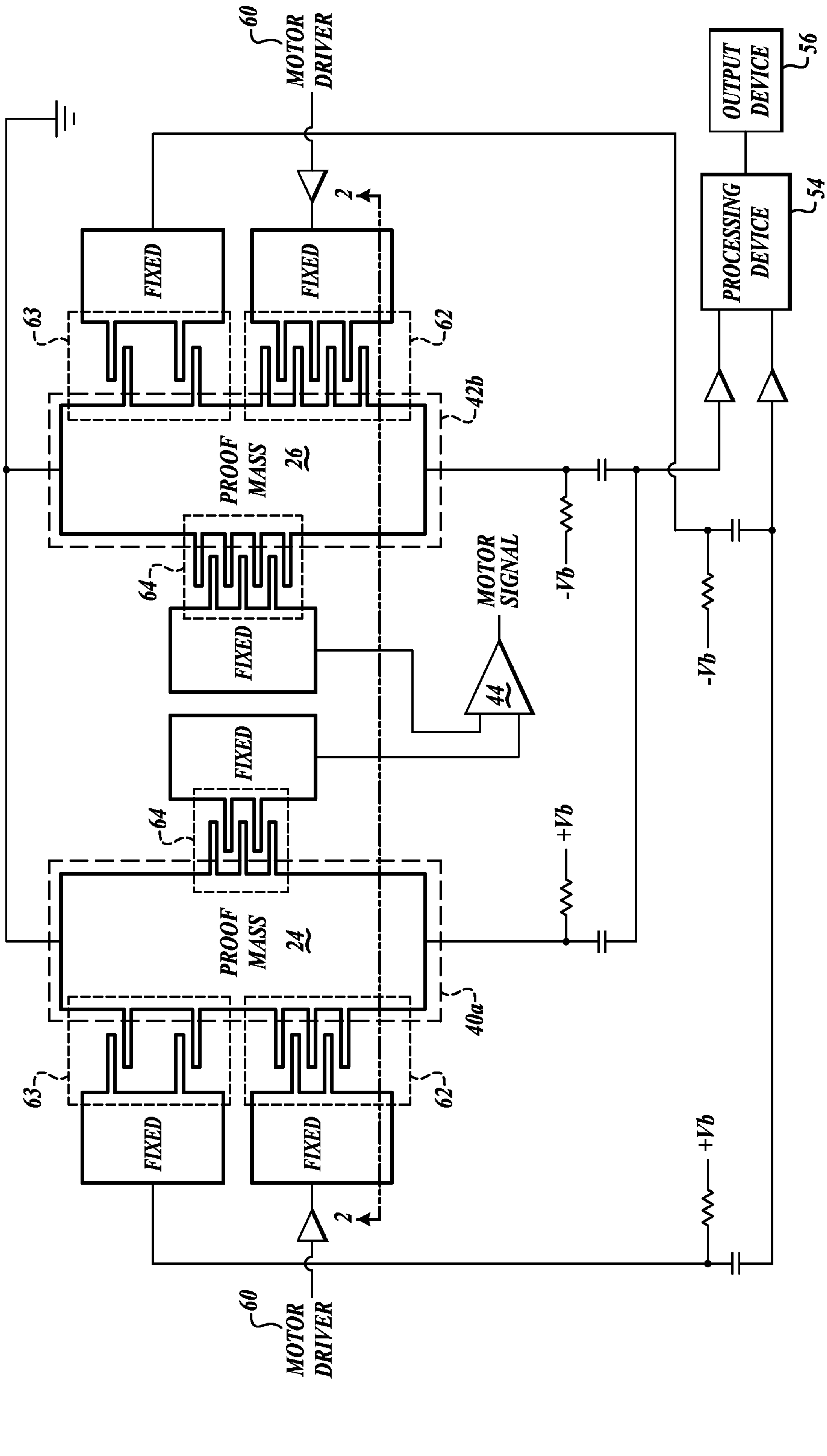
60
MOTOR DRIVER
FIXED
FIXED
63
62
42b
PROOF MASS 26
64
FIXED
MOTOR SIGNAL
44
-Vb
-Vb
FIXED
64
+Vb
PROOF MASS 24
40a
63
62
FIXED
FIXED
2
2
+Vb
60
MOTOR DRIVER
PROCESSING DEVICE
54
OUTPUT DEVICE
56

FIG.3

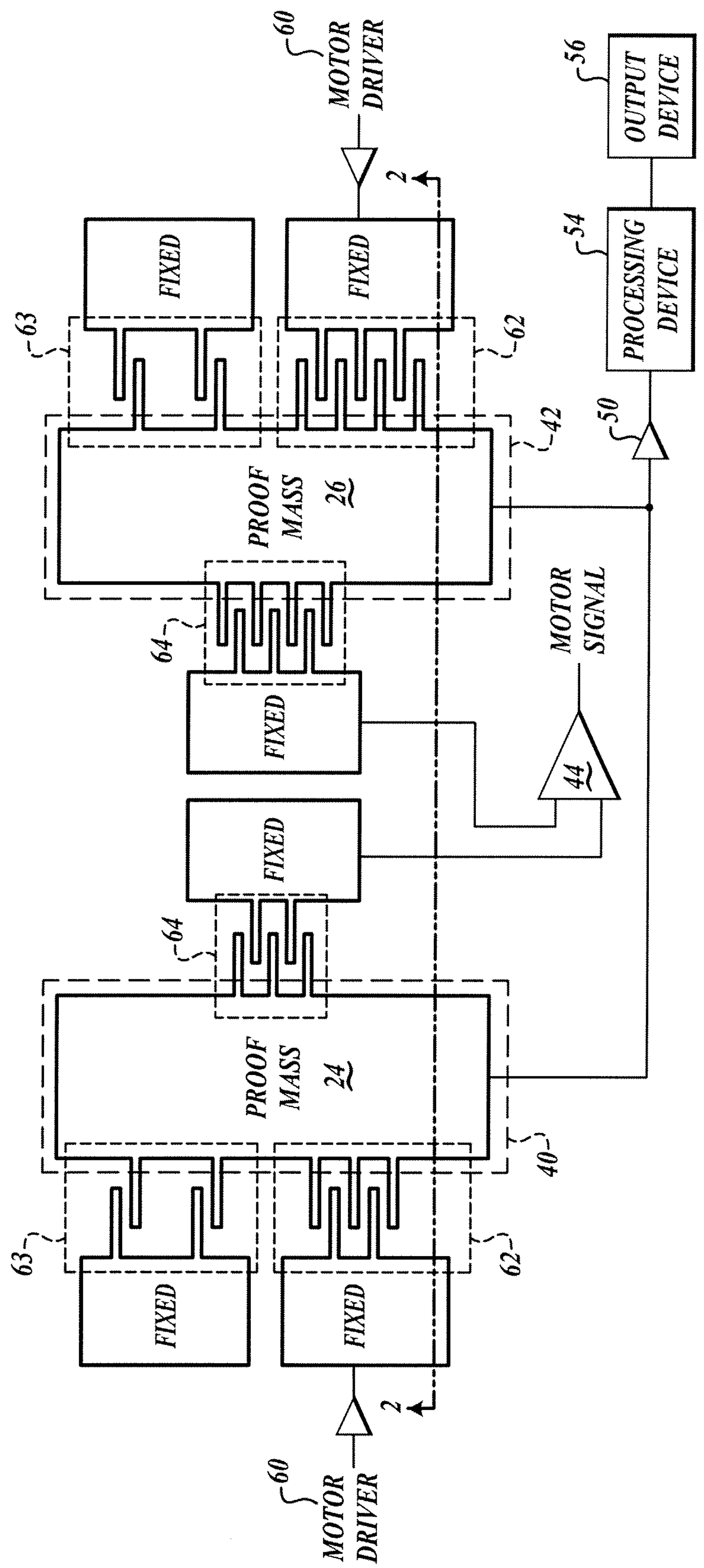
MOTOR DRIVER
60
2
FIXED
FIXED
FIXED
FIXED
FIXED
FIXED
63
62
64
64
63
62
PROOF MASS
26
PROOF MASS
24
42
40
MOTOR SIGNAL
44
50
PROCESSING DEVICE
54
OUTPUT DEVICE
56
MOTOR DRIVER
60
2

FIG.1

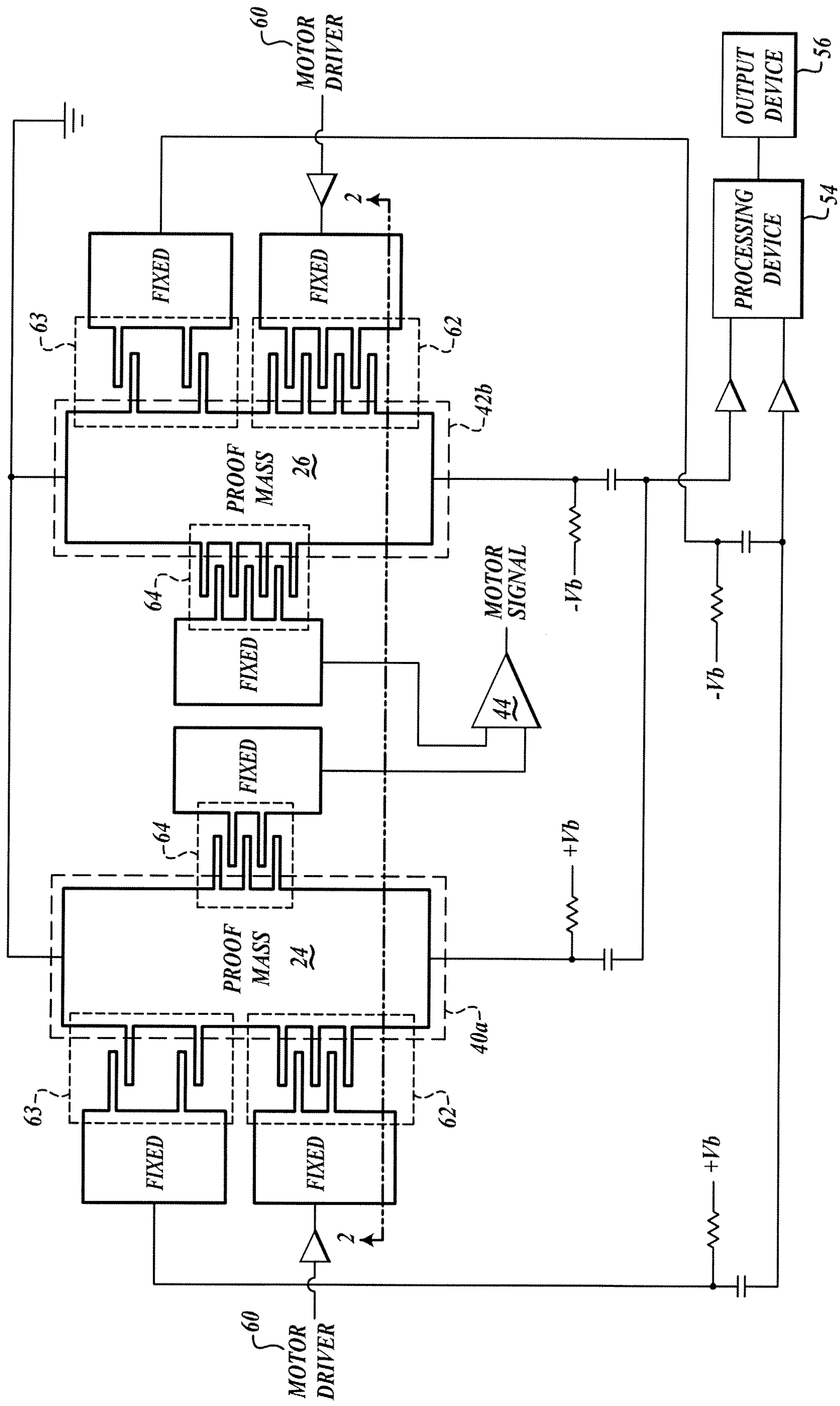
MOTOR DRIVER
60
OUTPUT DEVICE
56
PROCESSING DEVICE
54
FIXED
PROOF MASS
26
24
63
62
64
42b
40a
MOTOR SIGNAL
44
-Vb
+Vb
2

FIG.3